ANALYSIS OF OCCUPANT PROTECTION PROVIDED TO 50TH PERCENTILE MALE DUMMIES SITTING MID-TRACK AND 5TH PERCENTILE FEMALE DUMMIES SITTING FULL-FORWARD IN CRASH TESTS OF PAIRED VEHICLES WITH REDESIGNED AIR BAG SYSTEMS

Lori Summers, William T. Hollowell, Aloke Prasad
National Highway Traffic Safety Administration
United States of America
Paper Number 338

ABSTRACT

Historically, the United States Federal Motor Vehicle Safety Standard No. 208 (FMVSS No. 208) has used 50^{th} percentile male dummies seated in the mid-track position to evaluate occupant protection in frontal crashes. As a result of field investigations of air bag-related fatalities and serious injuries involving short-stature female drivers, more recent research has focused on improving crash protection using the 5^{th} percentile female dummy in a full-forward seat position.

A series of 48 kmph (30 mph) full frontal rigid barrier crash tests were conducted with belted and unbelted 5^{th} percentile female dummies in the full-forward seat position of Model Year (MY) 1999 vehicles with redesigned air bags (certified to the FMVSS No. 208 sled test). Tests were also conducted using identical vehicles with the 50^{th} percentile male dummies seated mid-track. In the belted test series, the 5^{th} percentile female dummy had higher chest acceleration and neck injury values (Nij) when compared to the 50^{th} percentile male dummy. Chest accelerations were increased approximately 23 percent and Nij values were also 2-3 times higher for the 5^{th} percentile female dummy. Lower steering wheel rim contact, shallow chest-to-steering wheel distances, and high torso belt tension were noted in cases of high chest acceleration and Nij.

In the unbelted test series, the 5^{th} percentile female Nij values were either 2-5 times higher, or approximately equivalent to the 50^{th} percentile male dummy. One Nij test failure was repeated with the 5^{th} percentile female seated 76 mm (3 in.) back from full-forward and consequently the driver Nij value was reduced from 1.29 to 0.74. Two vehicles also resulted in large hyperextensions of the 5^{th} percentile female passenger dummy's neck from a combination of disproportionate air bag loadings to the head/chest region, instrument panel contacts through the air bag, and submarining. Chest accelerations for the unbelted 5^{th} percentile female test series were typically lower or approximately equivalent to the 50^{th} percentile male in the driver position and were typically higher or approximately equivalent to the 50^{th} percentile male in the passenger position. Passenger chest-to-instrument panel contacts were noted in some cases.

INTRODUCTION

NHTSA's Federal Motor Vehicle Safety Standard for occupant protection in the United States (FMVSS No. 208) has historically required the use of 50^{th} percentile male dummies seated in the mid-track position in its frontal crash tests. However, recent reports of air bag related fatalities and serious injuries prepared by NHTSA's Special Crash Investigations have raised concern about the effectiveness of air bags to occupants of different sizes and seat positions (other than mid-sized males seated mid-track). While it has been determined that close proximity to the air bag at the time of deployment has been a common factor in <u>all</u> the air bag related fatalities, a number of secondary trends in stature, gender, and age have also raised public concern. For example, as of December 1, 2000, 49 of the 63 drivers (78%) who sustained fatal injuries from interaction with a deploying air bag in minor or moderate severity crashes were female. Of these 49 females, 40 (82%) were 163 cm (5 ft. 4 in.) or less in height. Thirty-seven of the 63 total driver fatalities (59%) were over 50 years of age [1].

Studies have found that of these three secondary factors (stature, gender, and age), driver stature has the most dominant effect on driver proximity to the steering wheel. Shorter drivers generally sit closer to the steering wheel than taller drivers [2]. However, arguments have also been made that very small stature women appear to constitute the largest segment of the population that tend to sit closer to the steering wheel, and that differences in body size may also lead to more severe injury to a small stature woman [3]. Therefore, near-term rulemaking actions were directed toward protecting the short stature female population of occupants (including the elderly) and others that may occupy the full-forward seat position.

One way to evaluate risks and occupant protection provided by an air bag system is through the use of biofidelic mechanical surrogates such as the Hybrid III crash test dummies [3]. The 5^{th} percentile female Hybrid III crash test dummy is approximately 150 cm (4 ft. 11 in.) tall and weighs 49 kg (108 lbs). This dummy has been utilized in a variety of NHTSA frontal research programs [4-10] and was also petitioned for use in FMVSS No. 208 [12,13]. Therefore, NHTSA rulemaking efforts have been expedited toward the incorporation of the 5th percentile female Hybrid III crash test dummy into Part 572.

A number of earlier studies have also used the 5th percentile Hybrid III dummy to evaluate frontal occupant crash protection. Stucki et al. [4], conducted a pair of 48 kmph (30 mph) rigid barrier crash tests with unbelted 5th percentile female and 50th percentile male dummies in Model Year (MY) 1993 Ford Taurus vehicles. For the driver, the 5th percentile female injury measures were slightly lower than the 50th percentile male. However, on the passenger side, the 5th percentile female dummy chest acceleration value was considerably higher than that of the 50th percentile male dummy (49.9 Gs vs. 32.0 Gs)[1].

Park, et al. [5] also conducted comparative frontal crash tests with belted 5th percentile female and 50th percentile male dummies. In 48 kmph (30 mph) rigid barrier crash tests with MY 1996 vehicles, this study found that the small female dummy resulted in high neck readings; whereas the 50th percentile male dummy responses did not exceed the referenced values.

In the two previous studies, older (pre-MY 1998) vehicles were used and the referenced injury criteria and reference values have since changed. Beginning on March 19, 1997, NHTSA temporarily amended FMVSS No. 208 to make it easier for vehicle manufacturers to quickly redesign air bag systems so that they inflate less aggressively [15]. Many vehicle manufacturers redesigned the air bag systems for their MY 1998 vehicles by reducing inflator peak pressure and/or rise rate and reducing air bag volume. Other changes in air bag designs that they have made in recent model years include recessing the air bag module, modifying the fold pattern, adding tether straps, changing the vent sizes, etc. [11].

An early evaluation of MY 1998 vehicles with redesigned air bag systems was conducted by Transport Canada and NHTSA through a joint research program. In 48 kmph (30 mph) rigid barrier crash tests with the 5th percentile female dummy, neck criteria were exceeded in 45% of the MY 1998 vehicles tested [7]. Comparable crash test data with the 50th percentile male dummy did not exceed the injury reference values. While the study also showed that the neck responses had improved in redesigned MY 1998 vehicles over previous model years (from a 59% failure rate to 45%), the testing suggested that further improvements would still be needed.

Recently, Park, et al. [6] conducted a series of high speed belted rigid barrier tests with MY 1996 and MY 1998 vehicles using combinations of 50th percentile male and 5th percentile female dummies. The study found that the Head Injury Criteria (HIC), chest acceleration, chest deformation and femur forces were generally below the injury reference values for both dummy sizes while lower tibia readings were typically exceeded. For the MY 1996 vehicles (with pre-redesigned air bag systems) the 5th percentile female dummies resulted in high neck injury measures (Nij values); whereas only one in three of the MY 1998 vehicles (with redesigned air bag systems) resulted in high Nij values. The study also found that 50th percentile male dummies in comparable MY 1998 vehicles resulted in relatively low neck injury measures.

On May 12, 2000, NHTSA issued an interim final rule for FMVSS No. 208 that requires, for the first time, high speed belted and unbelted occupant crash protection using 5th percentile female Hybrid III crash test dummies in the full-forward seat position. It also requires new Injury Criteria Performance Limits (ICPLs), particularly for the neck, and a thoracic criteria for the 5th percentile female that takes age and gender into account. The new thoracic ICPL is scaled to account for the greater bone loss with the increase in age among females as compared to males [16].

This study uses the FMVSS No. 208 Interim Final Rule ICPLs to examine the next model year of vehicles with redesigned air bag systems (MY 1999) and compare the occupant protection provided to the 5th percentile female seated full-forward to the 50th percentile male seated mid-track under identical crash conditions. This study evaluates both a belted and unbelted series of crash tests.

VEHICLE CRASH TEST MATRIX

As part of NHTSA's evaluation of overall frontal occupant protection, a series of 48 kmph (30 mph) rigid barrier crash tests were conducted with 5th percentile female and 50th percentile male crash test dummies in matching make/model/year vehicles. The 5th percentile female crash test dummies were positioned as driver and right front passenger with the seats in the full-forward position. Comparable tests were also conducted with 50th percentile male dummies seated at mid-track.

Series I, the belted test series, was conducted through a joint research program between NHTSA and Transport Canada. Five pairs of MY 1999 vehicles were selected for testing. The vehicle models are listed in Table 1.

Series II, the unbelted test series, was conducted by NHTSA at the Vehicle Research and Test Center. Six pairs of MY 1999 vehicles were tested, and are listed in Table 2.

[1] Note: Neck injury measures were not documented in the study. Current review of the crash test films and dummy kinematics for the 5th percentile female passenger dummy suggest that neck extension failures may have resulted in this test.

Table 1. Series I: 48 kmph (30 mph) Rigid Barrier Full Frontal Crash Tests with Belted Driver and Right Front Passenger

Vehicle	5th % Female	50th % Male
MY 1999 Hyundai Accent	✓	✓
MY 1999 Plymouth Breeze	✓	✓
MY 1999 Ford Ranger	✓	✓
MY 1999 Toyota Camry	✓	✓
MY 1999 Ford Taurus	✓	✓

Table 2. Series II: 48 kmph (30 mph) Rigid Barrier Full Frontal Crash Tests with Unbelted Driver and Right Front Passenger

Vehicle	5th % Female	50th % Male
MY 1999 Saturn SL1	✓	✓
MY 1999 Dodge Intrepid	✓	✓
MY 1999 Toyota Tacoma	✓	✓
MY 1999 Acura 3.5 RL	✓	✓
MY 1999 Ford Econoline	✓	✓
MY 1999 Chevrolet Blazer	✓	✓

The vehicles in both series were selected from the 1999 model year in order to capture vehicles that were equipped with redesigned air bag systems (certified to the FMVSS No. 208 sled test).

RESULTS AND DISCUSSION

The occupant injury measures from the five pair of belted rigid barrier crash tests are reported in Table A1 of the Appendix and are grouped by vehicle model. For each vehicle, the first row corresponds to the 5th percentile female dummy results and the second corresponds to the 50th percentile male dummy. Table A2 similarly reports the results from the six pair of unbelted rigid barrier crash tests.

Additional 48 kmph (30 mph) belted rigid barrier crash test results with MY 1998 and MY 1999 vehicles are reported in Tables A3 and A4. These vehicles were equipped with redesigned air bags and the tests were also conducted in NHTSA's joint research program with Transport Canada. Table A3 reports the results from 22 tests with the 5th percentile female seated full-forward and Table A4 reports the results from 13 tests with the 50th percentile male seated mid-track. (These are individual vehicle crash tests that were only conducted with one of the two dummy sizes. The results are used in this study to compare trends from Series I tests to a larger representation of the vehicle fleet with redesigned air bags.)

Table 3. FMVSS No. 208 Interim Final Rule Injury Criteria Performance Limits (ICPLs)

	5th % Female	50th % Male
Head Criteria: HIC (15 ms)	700	700
Neck Criteria: Nij	1.0	1.0
In- Position Critical Intercept Values		
Tension (N)	4,287	6,806
Compression (N)	3,880	6,160
Flexion (Nm)	155	310
Extension (Nm)	67	135
Peak Tension (N)	2,620	4,170
Peak Compression (N)	2,520	4,000
Thoracic Criteria		
1. Chest Acceleration (G)	60	60
2. Chest Deflection (mm)	52	63
Lower Ext. Criteria: Femur Load (N)	6,805	10,008

As previously mentioned, the results in this study were evaluated based on the ICPLs established in the May 12, 2000 Interim Final Rule for FMVSS No. 208. These are presented in Table 3. Some of the injury measures have different ICPL values according to dummy size (i.e., chest deflection, femur loads, etc.), and consequently were normalized for comparison in the Appendix.

Series I: Belted 48 kmph (30 mph) Full Frontal Rigid Barrier Crash Tests

Head: The dummy readings from the five belted 48 kmph (30 mph) rigid barrier crash tests using 5th percentile female dummies were evaluated against comparable tests using 50th percentile male dummies. HIC15 readings were low for both dummy types and were generally below 50% of the ICPLs, suggesting a low risk of injury for the head. (HIC15 results are listed in Table A1 of the Appendix). The 5th percentile female head accelerations generally began and peaked earlier in time due to the closer seat position; however the HIC15 computations were not substantially different than those resulting from the 50th percentile male tests in this series.

Low HIC15 values also resulted in the additional belted 48 kmph (30 mph) rigid barrier crash tests provided in Tables A3 and A4 of the Appendix. The average 5th percentile female driver and passenger

HIC15 readings were 235 and 245, respectively (from a series of 27 tests). The average 50^{th} percentile male driver and passenger HIC15 readings were 239 and 157, respectively (from a series of 18 tests). Therefore, the five pair of 5^{th} percentile female and 50^{th} percentile male belted tests from Series I appear to reasonably reflect the average head response from a larger spectrum of MY 1998 – MY 1999 vehicles.

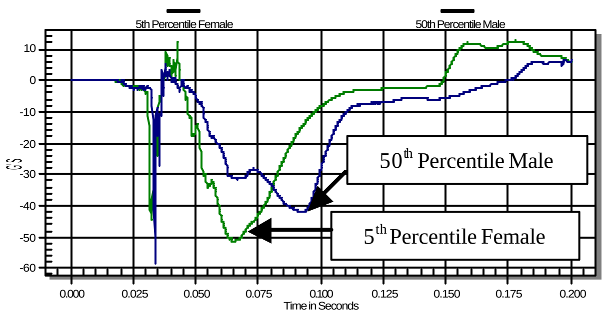


Figure 1: Passenger head acceleration signals with evidence of early head-to-air bag contact in the Toyota Camry tests (filtered at CFC1000).

A final observation was made about the head acceleration traces from the rigid barrier tests. In one vehicle an early spike was noted in both the 5^{th} percentile female and 50^{th} percentile male passenger dummy responses that appeared to be a "bag-slap" contact (i.e., the surface of the inflating air bag moving at high velocity and "slapping" the occupant). In this vehicle, the passenger air bag initially deployed vertically toward the roof and made early contact with the dummy's head. The longitudinal head acceleration traces are shown in Figure 1 for both dummies. While the early head acceleration spike was not of sufficient duration to affect the HIC15 computation, and did not adversely affect the neck computations, there is concern about occupants having early contact with the air bag while it is inflating. Ocular injuries, for example, are of particular concern -- while they are rare occurrences -- they can lead to permanent impairment [17].

Chest: In the belted 48 kmph (30 mph) rigid barrier crash tests, the differences between the 5^{th} percentile female dummies sitting full-forward and 50^{th} percentile male dummies sitting mid-track were more pronounced in terms of the chest and neck injury measures. Melvin et al. [18] found a relationship between injury severity and dummy alignment with, and distance from, the air bag module. The results demonstrated that the proximity of an occupant to the air bag module has a strong influence on the response of the neck and chest.

In the five pair of belted 48 kmph (30 mph) rigid barrier crash tests using 5^{th} percentile female and 50^{th} percentile male dummies, the chest acceleration readings were below the ICPLs for both dummy types. However, the driver chest acceleration levels were consistently higher for the 5^{th} percentile female dummy (Figure 2).

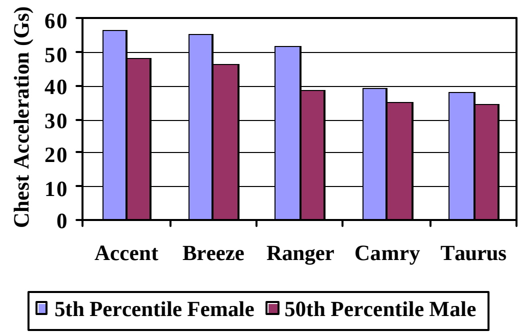


Figure 2: Belted driver chest acceleration results for the five pairs of 48 kmph (30 mph) full frontal rigid barrier crash tests.

In three of the vehicles, the differential in chest acceleration between the two dummy types was relatively large. The 5^{th} percentile female driver dummy resulted in high chest acceleration values (56.4, 55.0, and 52.0 Gs); whereas the corresponding 50^{th} percentile male test results were considerably lower (48.3, 46.5, and 38.3 Gs). In these three vehicles, the full-forward seat track positioned the 5^{th} percentile female driver relatively close to the steering wheel. The chest-to-steering wheel distances were 185 mm (7.3 in.), 200 mm (7.9 in.), and 150 mm (5.9 in.), respectively. The 50^{th} percentile male driver dummies, in comparable tests, each had over 279 mm (11 in.) of chest-to-steering wheel distance.

Consequently, in two of the three vehicles, the 5^{th} percentile female driver's thorax/abdomen directly contacted the lower rim of the steering wheel[2] (and inhibited the proper deployment path of the air bag). The forces from the lower rim contact and the re-directed air bag loading contributed to the high chest acceleration readings.

In the third vehicle, the combination of air bag opening time, and shoulder belt loading may have resulted in the high chest acceleration readings. The driver air bag in this vehicle opened approximately 5 msec later than the average vehicle in the series[3] which gave the dummy more time to translate forward and rely on early contributions from the shoulder belt. The corresponding tension loads reported in the driver's

[2] Steering wheel rim contact was monitored in the belted test series. The lower steering wheel rims were coated with contact paint and the lower thorax/abdomen area of the dummy was fitted with a white contact surface. Evidence of contact was observed post-crash by inspecting the dummy for paint.

[3] Air bag opening times are reported in Table A1 of the Appendix. These reflect the times at which the air bag cover is burst open.

shoulder belt were, as a result, the highest of the 5th percentile female tests in the series (4170 N or 937 lbs.). However, high shoulder belt loads did not result for the 50th percentile male driver in the same vehicle and crash conditions. In this case, the shoulder belt loads were maintained at approximately 5000 N (1124 lbs.), which was approximately average for the 50th percentile male driver dummy in the series. This suggests that the energy management features in the belts may have been optimized to reduce the concentrated loading on the 50th percentile male after a certain force limit. However, the belt characteristics up to that force limit may have been too stiff for the 5th percentile female dummy seated full-forward.

Two of the five vehicles in the series had relatively good chest acceleration performance and were able to keep the driver results below 40 Gs for both dummy types. Both vehicles were equipped with energy management features that allowed the seat belts to yield and prevent excessive concentrated shoulder belt forces on the chest. One of the vehicles was also equipped with a seat belt pretensioner, which applied restraining forces earlier to the occupant by retracting the seat belt and removing excess slack [18]. Both of these vehicles also had relatively good chest acceleration performance for the passenger dummy (below 40 Gs for both dummies).

In most cases, the 5th percentile female passenger chest accelerations were higher than those resulting from the 50th percentile male passenger dummy in the vehicle pairs tested (Figure 3)[4]. This was similar to what was observed for the driver. There was one exception that resulted in higher chest acceleration for the 50th percentile male than the 5th percentile female. In this test, a spike resulted in the chest acceleration trace that corresponded in time with the peak belt tension. Since the dummy in this test had the largest chest-to-dash distance of the series, the dummy may have relied more on the safety belt for restraint. It is possible that the force limiting capabilities of the belt were exhausted at that point, and more of the concentrated safety belt loading contributed to the high chest acceleration peak.

The chest acceleration results from Series I were compared to the average of a broader spectrum of 27 belted 48 kmph (30 mph) rigid barrier crash tests with the 5th percentile female dummy and 18 tests with the 50th percentile male dummy (Tables A1, A3, and A4 of the Appendix). The average belted driver chest acceleration was 46.0 Gs for the 5th percentile female dummy and 36.8 Gs for the 50th percentile male dummy. Therefore, the average belted driver chest acceleration was 25% higher for the 5th percentile female dummy. On the passenger's side, the average chest acceleration was also higher for the 5th percentile female dummy by 21% (average 5th percentile female = 43.0 Gs; average 50th percentile male = 35.6 Gs). Therefore the higher 5th percentile female chest accelerations that resulted in the Series I tests were similar to what is seen in an average fleet of MY 1998 - MY 1999 vehicles with redesigned air bag systems.

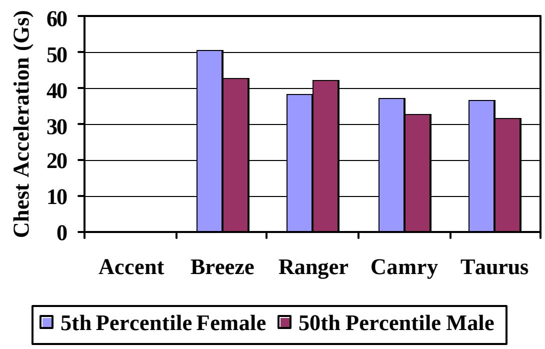


Figure 3: Belted passenger chest acceleration results for the pairs of 48 kmph (30 mph) full frontal rigid barrier crash tests.

Chest deflection readings were also below the ICPLs for both the 5th percentile female and 50th percentile male dummies in the five pair of belted 48 kmph (30 mph) rigid barrier crash tests. The results were also relatively comparable between the two dummy sizes. The normalized chest deflections for both dummies ranged between 0.34 and 0.72. The highest chest deflections resulted in tests where there was evidence of steering rim contact (discussed above) or high shoulder belt tension. This is consistent with the average response from the full set of test results provided in Tables A1, A3 and A4 of the Appendix (27 tests with the 5th percentile female dummy and 18 tests with the 50th percentile male dummy). The average driver and passenger normalized chest deflections were 0.57 and 0.48, respectively, for the 5th percentile female dummy, and 0.55 and 0.50, respectively, for the 50th percentile male dummy.

Neck: In the five pair of belted 48 kmph (30 mph) rigid barrier crash tests, the neck readings of the 5th percentile female driver dummies were consistently higher than the 50th percentile male dummies (Figure 4). Individual neck injury measures are listed in Table A1 of the Appendix. These results are consistent with previous studies by Dalmotas [7] and Park, et al. [6].

Two of the five tests resulted in the 5th percentile female driver dummy exceeding the Nij criteria of 1.0, whereas all of the Nij readings from the 50th percentile male driver dummies were below 0.4. These results are

[4] Note: One of the five pairs of vehicles did not have passenger air bags since they were purchased in the Canadian market where air bags are not federally mandated. The results were not included in the bar charts, but are provided in the Appendix.

consistent with the average response from the full set of test results provided in Tables A1, A3, and A4 of the Appendix (27 tests with the 5th percentile female dummy and 18 tests with the 50th percentile male dummy). These results showed that the average driver Nij response was three times higher for the 5th percentile female dummy. The average 5th percentile female Nij value was 0.89 and the average 50th percentile male Nij value was 0.30.

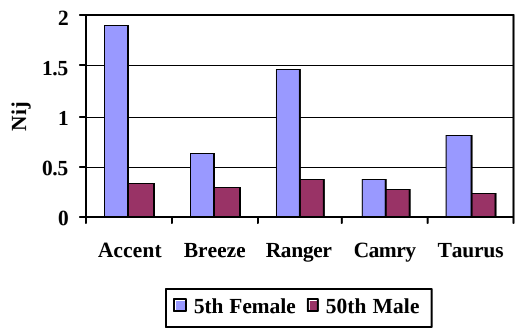


Figure 4: Belted driver Nij results for the five pair of 48 kmph (30 mph) full frontal rigid barrier crash tests.

The Nij failures in the two tests with the 5th percentile female driver dummy (i.e., Nij = 1.90 and Nij = 1.46) also corresponded to two of the three instances of dummy contact with the lower steering wheel rim. (The third instance was a minor contact mark that resulted in the third highest 5th percentile female driver Nij of the series with a value of 0.80.) In these cases, the air bag was inhibited from deploying downwards and preventing contact between the dummy and the lower steering wheel rim. The air bag was then forced to deploy upwards toward the head/neck region and consequently caused high neck extension moments. Initial chest-to-steering wheel distance may also have been a factor in the steering wheel contacts. The three vehicles that resulted in the highest Nij readings were also the three vehicles with the smallest chest-to-steering wheel distances for the 5th percentile female dummy seated full-forward.

Conversely, the vehicle that had the lowest 5th percentile female driver Nij of the series (Nij = 0.37) also had the largest chest-to-steering wheel distance (207 mm or 8.1 in.). For this vehicle, the extra distance, in addition to the incorporation of a seat belt pretensioner and a timely air bag deployment, may have contributed to keeping the dummy out of the path of the deploying air bag and minimizing the Nij value.

All of the Nij readings for the 5th percentile female driver dummy were in the tension-extension mode for the subset of five vehicles; whereas the corresponding Nij readings for the 50th percentile male under comparable crash conditions were typically tension-flexion. Since the 50th percentile male dummy typically was seated 279 mm (11 in.) or more from the air bag module, the air bag was provided more room to deploy prior to dummy contact. As a result, head and neck kinematics were well-controlled and excessive forward flexion or rearward extension of the neck was typically avoided [7].

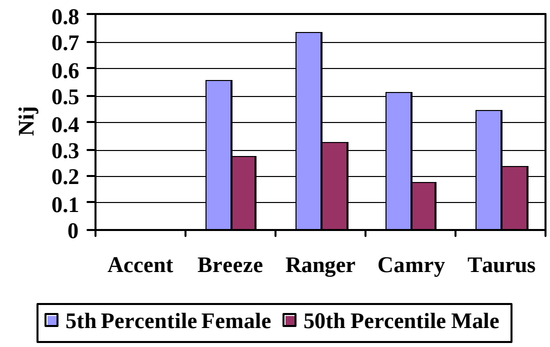


Figure 5: Belted passenger Nij results for the five pair of 48 kmph (30 mph) full frontal rigid barrier crash tests.

On the passenger side, the Nij readings of the 5th percentile female dummies were again consistently higher than those of the 50th percentile male dummies (Figure 5)[5]. Individual neck injury measures are listed in Table A1 of the Appendix. However, all of the passenger Nij measurements were below the ICPLs for both dummy types. This is consistent with the full series of test results provided in Tables A1, A3, and A4 of the Appendix (27 tests with the 5th percentile female dummy and 18 tests with the 50th percentile male dummy). The average passenger Nij response was two times higher for the 5th percentile female dummy. (The average 5th percentile female Nij value was 0.56 and the average 50th percentile male Nij value was 0.27.)

In the five pairs of tests, the maximum passenger Nij readings were typically a function of axial tension accompanied by rearward extension. The only exception was a test where the 5th percentile female passenger experienced an axial compression with a forward flexion of the neck which may have resulted from a combination of seat belt pretensioning and the fact that the air bag deployed over the top of the dummy's head. Even though the passenger dummy neck injury modes were relatively consistent for this test series (i.e., most in the tension extension mode), previous studies [7] have reported that depending on the compartment geometry and air bag design, the head and neck kinematics can be far more complex (than for the driver), and a variety of neck injury modes could be represented. This is also illustrated by the Nij results of

[5] Note: One of the five pairs of vehicles did not have passenger air bags since they were purchased in the Canadian market where air bags are not federally mandated. The results were not included in the bar charts, but are provided in the Appendix.

the additional tests reported in Tables A3 and A4 of the Appendix.

Femur: Normalized femur forces measured on the 5th percentile female driver dummies were typically less than or approximately equivalent to the 50th percentile male dummies in the five pair of belted 48 kmph (30 mph) full frontal rigid barrier crash tests. (Normalized femur forces are listed in Table A1 of the Appendix). Most of the femur measurements were typically less than half of their respective ICPLs. Since these were all belted tests, the lap belt restraint helped reduce lower body excursion and contact loads with the instrument panel.

Series II: Unbelted 48 kmph (30 mph) Full Frontal Rigid Barrier Crash Test Series

Head: The dummy readings from the six unbelted 48 kmph (30 mph) rigid barrier crash tests using 5th percentile female dummies sitting full-forward were evaluated against comparable tests using 50th percentile male dummies seated mid-track. As in the belted tests, the HIC15 results were low for both dummy types and almost all were below 50% of the ICPLs for both driver and passenger. The specific HIC15 results are listed in Table A2 of the Appendix. The 5th percentile female dummy head accelerations also occurred earlier in time, due to the closer seat position; however the resulting HIC15 values were not substantially different than those from the 50th percentile male dummy tests.

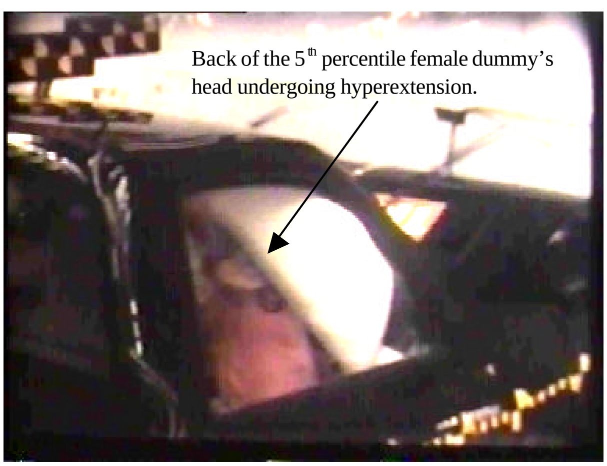


Figure 6: Hyperextension of the 5th female passenger dummy's head in the Toyota Tacoma test.

However, there were a number of observations made about the 5th percentile female dummy kinematics in the unbelted test series. First, the highest HIC15 value of the unbelted series (HIC15 = 380) was a result of the 5th percentile female passenger dummy's head being forced rearward against the spine. As the dummy translated forward, the dummy's head was caught and restrained by the air bag while the chest continued forward. The head was then hyperextended rearward to the point where it was forced against the spine (as illustrated in Figure 6). This resulted in a positive 75G spike in the head acceleration signal (Figure 7). While the 5th percentile female dummy in this test did not result in a failing HIC15 measurement, the dummy did exceed the ICPLs for the neck. The 50th percentile male passenger dummy in the comparable test for this vehicle resulted in low head and neck measurements. (The 50th percentile male head acceleration trace is also illustrated in Figure 7).

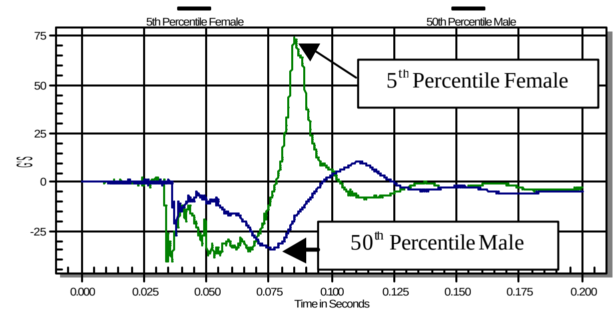


Figure 7: Head acceleration trace of the 5th percentile female passenger dummy's head hyperextended rearward and the comparable response from the 50th percentile male dummy (filtered at CFC1000).

A second positive head acceleration spike also resulted from the hyperextension of the 5th percentile female passenger dummy's head in a second vehicle crash test. In this case, the mid-mounted air bag initially restrained the dummy's chest; however, the dummy's head continued to translate forward. It then contacted the windshield and instrument panel (through the air bag) and resulted in the dummy's head being hyperextended rearward against the spine. A contact spike followed by a positive 34 G head acceleration peak resulted for the 5th percentile female passenger; however this did not occur for the 50th percentile male dummy under comparable conditions.

Finally, early bag contact with the passenger dummy's head (i.e. bag-slap) also resulted in two vehicles of the series. (This was previously discussed in the belted Series I tests and illustrated in Figure 1). This occurred for both 5th percentile female and 50th percentile male dummy types. In each vehicle, the contacts were earlier in time and greater in magnitude for the 5th percentile female dummy seated full-forward. However they again were not of sufficient duration to affect the HIC15 computation and did not adversely effect the neck computations.

Chest: In the unbelted 48 kmph (30 mph) rigid barrier crash tests, the 5th percentile female driver chest accelerations were generally lower or approximately equivalent to the 50th percentile male driver chest accelerations (Figure 8). The values are provided in Table A2 of the Appendix[6]. Almost all of the driver chest acceleration results were below the ICPLs. In three of the vehicles, the 50th percentile male driver exceeded the 5th percentile female driver chest acceleration by approximately 9-19 Gs. This is relatively consistent with Stucki, et al. [4] who reported a higher 50th percentile male driver chest acceleration result in a pair of unbelted 48 kmph (30 mph) rigid barrier crash tests with both dummies. In two other vehicles, the driver chest accelerations for both size dummies were approximately equivalent (or within 4% of each other).

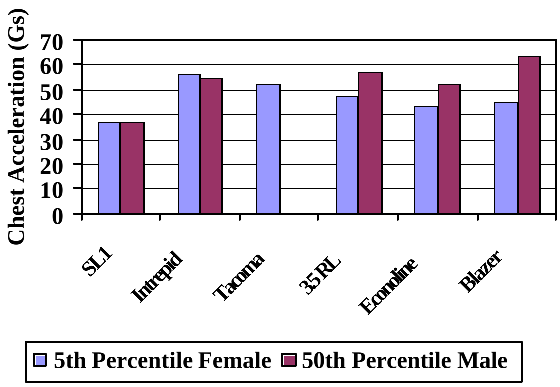


Figure 8: Unbelted driver chest acceleration results for the six pairs of 48 kmph (30 mph) full frontal rigid barrier crash tests.

Figure 9 is a plot comparing the 5th percentile female and 50th percentile male driver chest acceleration signals for one vehicle model in the series. At approximately 50 msec. (the time at which the air bag is typically filled in a rigid barrier crash) the 5th percentile female dummy already had 32 Gs of acceleration applied to the chest. The 50th percentile male dummy, at the same time frame, had experienced less than half of this level. The 5th percentile female dummy reached a 40 G chest acceleration level early in the event (at 58 msec) and kept it relatively constant over a 20-25 msec. time frame; whereas the larger male dummy, seated further back, fully interacted with the air bag at a later time and resulted in a higher and narrower peak chest acceleration of approximately 52 Gs (at 73 msec).

In the 50th percentile male driver chest acceleration failure of 63 Gs, the dummy fully stroked the air bag and steering column in a slightly vertical direction with its chest as the vehicle pitched down upon impact with the barrier and the occupant compartment started losing structural integrity around the A-pillar. Both high chest acceleration and chest deflection values resulted for this dummy. The 5th percentile female dummy (in the comparable vehicle crash condition) was restrained early in the event by the air bag and did not engage and crush the steering column as significantly.

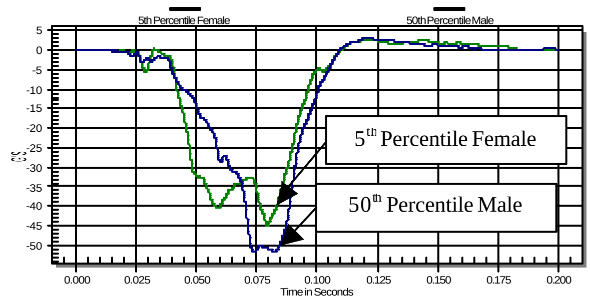


Figure 9: Comparison of unbelted 5th percentile female and 50th percentile male driver chest acceleration signals from the Ford Econoline test (filtered at CFC180).

On the passenger side, the 5th percentile female chest accelerations were greater in magnitude than those resulting from the 50th percentile male dummy in three of the vehicles (Figure 10)[6]. The specific values are provided in Table A2 of the Appendix. These results are consistent with Stucki, et al. [4] who reported a higher 5th percentile female passenger chest acceleration result in a pair of unbelted 48 kmph (30 mph) rigid barrier crash tests with both dummies.

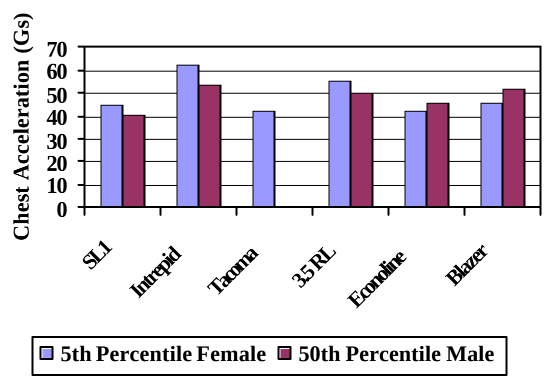


Figure 10: Unbelted passenger chest acceleration results for the six pairs of 48 kmph (30 mph) full frontal rigid barrier crash tests.

In two of the three pair of tests, the 5th percentile female passenger had chest contact with the instrument panel (through the air bag). Figure 11 illustrates the resulting chest acceleration signal. In the absence of the contact spike, the chest acceleration values for the 5th percentile female and 50th percentile male passengers may have been comparable in magnitude.

In the third vehicle where the 5th percentile female passenger had higher chest accelerations than that of the 50th percentile male dummy, the difference in chest acceleration was only marginal and both responses were well below the ICPLs. This vehicle also had relatively equivalent (and relatively low) *driver* chest

[6] Questionable comparative data for the 50th percentile male dummy in the Toyota Tacoma test.

acceleration readings for both dummies which suggests that the restraint system and energy management features of this vehicle appeared to be optimized for the two dummy sizes.

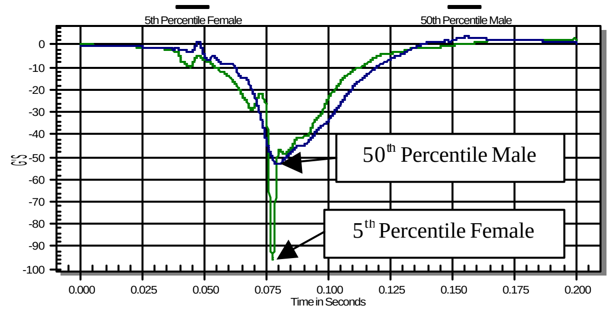


Figure 11: Unbelted passenger chest acceleration results in a 48 kmph (30 mph) full frontal rigid barrier crash test of the Dodge Intrepid (filtered at CFC180).

In the two other tests, the chest acceleration results were only marginally different between the two dummy sizes. Both vehicles were LTVs that had mid-mounted air bags that deployed toward the chest of the occupant. The longitudinal chest acceleration traces that resulted in both the 5^{th} percentile female and 50^{th} percentile male dummy tests were approximately equivalent in pulse shape and magnitude. Figure 12 is an example of one of the two tests.

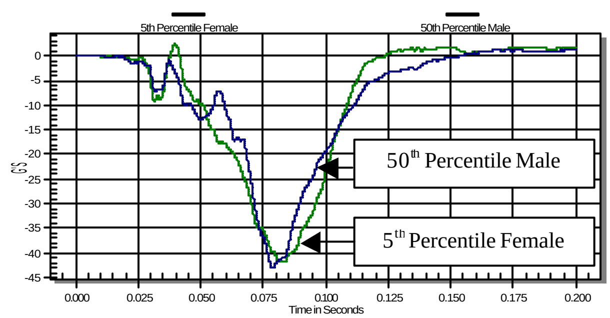


Figure 12: Unbelted passenger chest acceleration results in 48 kmph (30 mph) full frontal rigid barrier crash test of the Ford Econoline (filtered at CFC180).

Chest deflection readings for the unbelted 48 kmph (30 mph) rigid barrier crash test series are provided in Table A2 of the Appendix. On the driver side, most of the values were below the ICPLs for both dummy sizes, and the magnitude of the normalized chest deflections were relatively comparable. The average normalized driver chest deflection was 0.78 for the 5^{th} percentile female dummy and 0.71 for the 50^{th} percentile male dummy. However, three tests (two 5^{th} percentile female and one 50^{th} percentile male) resulted in relatively high chest deflection values which appeared to result from contact with the lower steering wheel rim and were correlated to high chest accelerations.

On the passenger side, the chest deflection values were <u>very</u> low and also were comparable between the two dummy types. The highest normalized chest deflection value was 0.41 for the 50^{th} percentile male dummy and 0.30 for the 5^{th} percentile female dummy.

<u>**Neck**</u>**:** In the unbelted pairs of 48 kmph (30 mph) rigid barrier crash tests, the Nij readings of the 5^{th} percentile female driver dummies were typically 45 times higher or, in two cases, approximately equivalent to the those resulting from the 50^{th} percentile male dummy under comparable test conditions (Figure 13)[6]. Individual neck injury measures are listed in Table A2 of the Appendix.

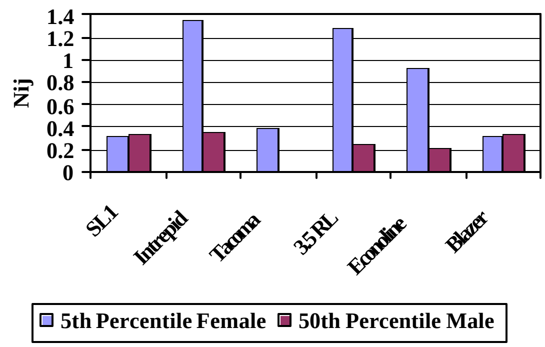


Figure 13: Unbelted driver Nij results in the series of 48 kmph (30 mph) full frontal rigid barrier crash tests.

Two of the tests resulted in the 5^{th} percentile female driver dummy exceeding the Nij criteria of 1.0; whereas all of the Nij readings from the 50^{th} percentile male driver dummies were below a value of 0.4. In the tests where the Nij results exceeded the ICPL for the 5^{th} percentile female driver, the air bag did not appear to deploy sufficiently between the dummy and the lower steering wheel rim. As discussed in the belted testing section, lower steering wheel rim contact may divert the air bag to deploy disproportionately upwards toward the head/neck region and cause high neck extension moments. Accordingly, all of the high Nij results for the 5^{th} percentile female driver dummy were in the tension-extension mode; whereas those with low Nij results were in the tension-flexion mode.

One of the vehicles with a high Nij result for the 5^{th} percentile female driver was repeated with the seat positioned 76 mm (3 in.) back from full-forward (Figure 14). The results are provided in Table A5 of the Appendix. The results demonstrated that the driver head and neck injury measures were generally reduced when the seat was positioned 76 mm (3 in.) back from full-forward. The Nij decreased from 1.29 to 0.74 and neck tension decreased from 1656 N to 1195 N. HIC15 was also decreased from 149 to 68 and the chest deflection was reduced slightly from 41.1 mm (1.6 in.) to 38.9 mm (1.5 in.). However, chest acceleration results were approximately equivalent for the two seat positions while the femur loads were increased slightly when positioned 76 mm (3 in.) back. Overall, as a result of the seat positioned 76 mm (3 in.) back from full-forward, the 5th percentile female injury measures were now all below the ICPLs.

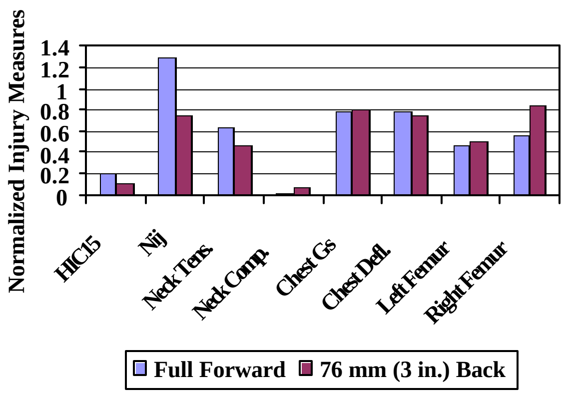


Figure 14: Comparison of the normalized results from the 5th percentile female dummy sitting full-forward vs. 76 mm (3 in.) back from full-forward in a full frontal rigid barrier crash test of the Acura 3.5 RL.

On the passenger side, the neck readings of the 5th percentile female dummy were again either 2-3 times higher or approximately equivalent to the 50th percentile male dummy (Figure 15)[6]. Individual neck injury measures are reported in Table A2 of the Appendix. In two vehicles, the Nij results for the 5th percentile female dummy exceeded the ICPLs; whereas none of the 50th percentile male dummy Nij results exceeded a value of 0.41.

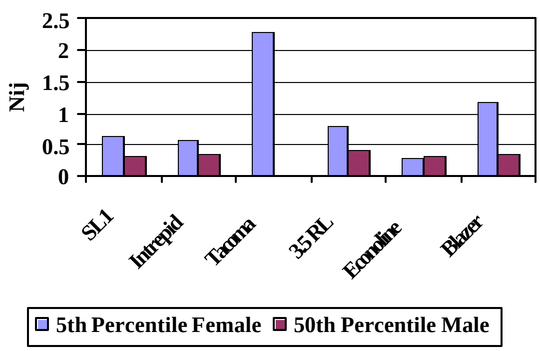
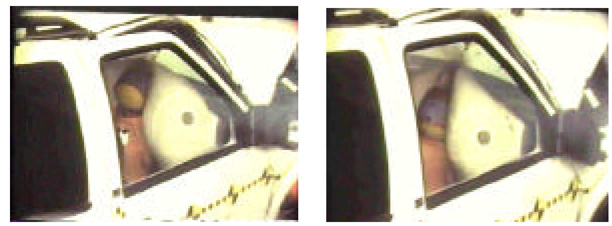


Figure 15: Unbelted passenger Nij results in the series of 48 kmph (30 mph) full frontal rigid barrier crash tests.

As discussed previously, the two 5th percentile female Nij failures resulted from hyperextension of the passenger dummy's head. In one case, the dummy's head was caught and stopped by the air bag while the chest continued forward. The head then rotated rearward and hyperextended to the point where it was forced against the spine (as illustrated in Figure 6). This resulted in a high axial tension of 3921 N with a measured rearward extension moment of 95 Nm.

In the second test, the mid-mounted air bag initially restrained the 5th percentile female passenger's chest; however, the dummy's head continued to translate forward and contacted the windshield through the air bag (as illustrated in Figure 16). The dummy's head then slid down the windshield and caught the chin area on the instrument panel in the area of the grab handle (Figure 17). This resulted in a slight axial compression with a measured rearward extension moment of 64 Nm.



Figures 16 and 17: Illustrations of 5th percentile female head-to-windshield contact through the passenger air bag and chin-to-instrument panel contact in the Chevrolet Blazer test.

The other lower Nij results of the test series were below the ICPLs for both dummy sizes and were representative of a combination of neck injury modes for the passenger dummy, depending on the compartment geometry and air bag design. (Nij injury modes are reported in Table A2 of the Appendix and other comparable tests are referenced in [20].)

Femur: Overall the femur forces were below the ICPLs in the six pairs of unbelted 48 kmph (30 mph) rigid barrier crash tests. (Normalized femur forces are listed in Table A2 of the Appendix). No significant differences were noted between the normalized femur forces from the 5th percentile female and 50th percentile male dummy tests. However, the unbelted 50th percentile male driver dummy exceeded the left femur ICPL with a value of 13,349 N in one test. Since the femur force from the adjoining right leg was only 5339 N, an asymmetric loading pattern resulted in this test.

SUMMARY AND CONCLUSIONS

The 5th percentile female Hybrid III crash test dummy has recently become a part of the U.S. Federal Motor Vehicle Safety Standards to evaluate the risks and occupant protection provided to small stature motor vehicle occupants. The present study conducted two series of 48 kmph (30 mph) rigid barrier crash tests with 5th percentile female driver and passenger dummies seated full-forward and 50th percentile male dummies seated mid-track. Series I included 5 pairs of belted crash tests and Series II included 6 pairs of unbelted crash tests in MY 1999 vehicles with redesigned air bag systems.

In Series I, the five pairs of belted tests with the 5^{th} percentile female dummy seated full-forward typically resulted in increased chest acceleration and Nij when compared to the tests with the 50^{th} percentile male seated mid-track. Lower steering wheel rim contact, shallow chest-to-steering wheel distances, and high torso belt tension were noted in the cases of high chest acceleration and Nij. Neck failures typically resulted when the air bag was unable to prevent contact between the dummy and the lower steering wheel rim. The air bag was then forced to deploy upwards toward the head/neck region and consequently caused high neck extension moments.

When considering a broader range of 48 kmph (30 mph) belted rigid barrier crash tests (27 tests with the 5^{th} percentile female dummy and 18 tests with the 50^{th} percentile male dummy), the average 5^{th} percentile female chest accelerations were 25% and 21% higher for the driver and right front passenger, respectively. The average 5^{th} percentile female dummy Nij measures were also 3 times higher for the driver and 2 times higher for the right front passenger when compared to the 50^{th} percentile male dummy. HIC15, chest deflection, and femur loads were not substantially different between the two dummy sizes and were below the ICPLs.

In Series II, the unbelted rigid barrier crash tests, HIC15 values were typically low for both dummy types; however, in two vehicles the 5^{th} percentile female passenger dummy resulted in hyperextension of the neck. This was reflected in the dummy head acceleration traces and high Nij values for the two vehicles. A combination of disproportionate air bag loadings to the head/chest region, instrument panel contacts through the air bag, and a lack of adequate femur-to-instrument panel contact contributed to these failures. On the driver side, three vehicles resulted in 5^{th} percentile female Nij results that were 4-5 times higher than the 50^{th} percentile male. In these tests, the air bag did not appear to deploy sufficiently between the dummy and the lower steering wheel rim. One Nij test failure was repeated with the 5^{th} percentile female seated 76 mm (3 in.) back from full-forward and the driver Nij value was reduced from 1.29 to 0.74.

Chest accelerations for the unbelted 5^{th} percentile female dummy were typically lower or approximately equivalent to the 50^{th} percentile male dummy in the driver position. The 5^{th} percentile female driver was seated full-forward and had the air bag restraint forces applied to the chest earlier in the event. The chest acceleration peaks were minimized compared to the larger 50^{th} percentile male dummy, seated mid-track, who interacted with the air bag at a later time and resulted in higher and more concentrated peak chest accelerations.

Chest accelerations for the unbelted 5^{th} percentile female dummy were typically higher or approximately equivalent to the 50^{th} percentile male dummy in the passenger position. Chest contacts with the instrument panel (through the air bag) were noted in some of the 5^{th} percentile female passenger tests with higher chest accelerations. Other vehicles with mid-mounted passenger air bag systems that initially deployed toward the chest did not result in significant differences between the chest acceleration traces of the 5^{th} percentile female and 50^{th} percentile male dummies.

The normalized chest deflections and femur loads were relatively comparable between the two dummy sizes in the unbelted series. A few tests with high driver chest deflections resulted; however the passenger chest deflections were very low. One test also resulted in an asymmetric loading of the driver left femur which exceeded the ICPL for the unbelted 50^{th} percentile male dummy.

In conclusion, the results from this testing illustrate the need for optimized frontal crash protection for occupants of different sizes and seat positions. Restraint systems can be enhanced by applying technologies that tailor their performance to the characteristics of the occupant. Examples of these technologies include: seat position sensors, occupant position and classification sensors, multistage air bag inflators, seat belt use sensors, dual level force limiters, pretensioners, etc. Design improvements to occupant compartment geometry, modifications to seat track length, and adjustable pedals could also have potential benefits for short stature occupants.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of Transport Canada for conducting the belted crash test data presented in this paper.

REFERENCES

[1] National Highway Traffic Safety Administration, Special Crash Investigations, December 1, 2000. http://www.nhtsa.dot.gov/people/ncsa/scireps.html.

[2] Manary, M.A., Flannagan, C.A.C., Reed, M.P., Schneider, L.W., *Predicting Proximity of Driver Head and Thorax to the Steering Wheel*, Proceedings of the 16th International Technical Conference on Experimental Safety Vehicles, Paper 98-S1-O-011, Windsor, Canada, 1998.

[3] National Highway Traffic Safety Administration, Notice of Proposed Rulemaking (5th percentile female Hybrid III), Federal Register, Volume 63, No. 171, page 46981, September 3, 1998, NHTSA Docket No. NHTSA-1998-4283-7.

[4] Stucki, S.L., Ragland, C., Hennessey, B., Hollowell, W.T., and Fessahaie, O., *NHTSA's Improved Frontal Protection Research Program*, SAE Paper #950497, Society of Automotive Engineers, Warrendale, PA, 1995.

[5] Park, B.T., Partyka, S.C., Morgan, R.M., Hackney, J.R., Lee, J., Stucki, S.L., and L., Lowrie, Frontal Offset Crash Test Study Using 50th Percentile Male and 5th Percentile Female Dummies, Proceedings of the 16th International Technical Conference on Experimental Safety Vehicles, Paper 98-S1-O-01, Windsor, Canada, 1998.

[6] Park, B.T., Partyka, S.C., Morgan, R.M., Hackney, J.R., Lee, J., Summers, L., Lowrie, J.C., and Beuse, N.M., *Comparison of Vehicle Structural Integrity and Occupant Injury Potential in Full-frontal and Offset-frontal Crash Tests*, Society of Automotive Engineer Paper 2000-01-0879, International Congress and Exposition, Detroit, March 2000.

[7] Dalmotas, D.J., *Assessments of Air Bag Performance Based on the 5th Percentile Female Hybrid III Crash Test Dummy*, Proceedings of the 16th International Technical Conference on Experimental Safety Vehicles, Paper 98-S5-O-07, Windsor, Canada, 1998.

[8] Rains, G.C., Prasad, A., Summers, L., Terrell, M., *Assessment of Advanced Air Bag Technology and Less Aggressive Air Bag Designs Through Performance Testing*, Proceedings of the 16th International Technical Conference on Experimental Safety Vehicles, Paper 98-S5-O-06, Windsor, Canada, 1998.

[9] Hollowell, W.T., Summers, L., Prasad, A., Narwani, G., Ato, T., *Performance Evaluation of Dual Stage Passenger Air Bag Systems*, Proceedings of the 17th International Technical Conference on Experimental Safety Vehicles, Amsterdam The Netherlands, June 2001.

[10] Summers, L., Hollowell, W.T., Rains, G.C., *NHTSA's Advanced Air Bag Technology Research Program*, Proceedings of the 16th International Technical Conference on Experimental Safety Vehicles, Paper 98-S5-W-29, Windsor, Canada, 1998.

[11] Hinch, J., Hollowell, W.T., Kanianthra, J., Evans, W.D., Klein, T., Longthorne, A., Ratchford, S., Morris, J., Subramanian, R., *Air Bag Technology in Light Passenger Vehicles*, Rev. 1, Docket NHTSA-1998-6407, Dec. 16, 1999.

[12] American Automotive Manufacturers Association, "Petition for Rulemaking, FMVSS 208," submitted to the National Highway Traffic Safety Administration, Aug. 23, 1996.

[13] Lindsey, A.G., "Petition Seeking to Change the Size of the Dummy in FMVSS No. 208," submitted to the National Highway Traffic Safety Administration, September 1, 1996.

[14] National Highway Traffic Safety Administration, Interim Final Rule (Advanced Air Bags), Federal Register, Volume 65, No. 93, page 30680, May 12, 2000, NHTSA Docket No. NHTSA-2000-7013.

[15] National Highway Traffic Safety Administration, Final Rule (Depowering), Federal Register, Volume 62, No. 53, page 12960, March 19, 1997, Docket No. NHTSA-1997-2817-001.

[16] Eppinger, R., Sun, E., Kuppa, S., Saul, R., Supplement: Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II, March 2000, NHTSA Docket No. NHTSA-2000-7013-3.

[17] Kress, T.A., Porta, D.J., Duma, S.M., Snider, J.N., Nino, N.M., A Discussion of the Air Bag System and Review of Induced Injuries, SAE Paper #960658, Society of Automotive Engineers, Warrendale, PA, 1996.

[18] Melvin, J.W., Horsch, J.D., McCleary, J.D., Wideman, L.C., Jensen, J.L., Wolanin, M.J., *Assessment of Air Bag Deployment Loads with the Small Female Hybrid III Dummy*, SAE Paper #933119, Society of Automotive Engineers, Warrendale, PA, 1993.

[19] National Highway Traffic Safety Administration and AAA, *New Car Safety Features1999*, DOT HS 808 808, www.nhtsa.dot.gov, November 1998.

[20] NHTSA Docket Number NHTSA-2000-7013-16. www.dms.gov, June 20, 2000.

Appendix

Table A1: Belted 48 kmph (30 mph) Rigid Barrier Crash Test Results.

	Test #	ATD Size	HIC 15	Nij	Norm. Neck Tens.	Norm. Neck Comp.	Chest Accel. (Gs)	Norm. Defl	Norm. Left Femur	Norm. Right Femur	Torso Belt Tens. (N)	Lap Belt Tension (N)	Pretens. (Y/N)	Energy Manag. Belt (Y/N)	Chest to Steering Wheel or Instr. Panel Distance (mm)	Steering Wheel Rim Contact (Y/N)	Air Bag Opening Time (msec)
DRIVER																	
MY 1999 Hyundai Accent	3094	5^{th}	285	1.90 NTE	0.98	0.11	56.4	0.53	0.23	0.12	4044	4811	N	Y	185	Y	18.5
	3107	50^{th}	334	0.34 NTF	0.47	0.01	48.3	0.52	0.08	0.12	6785	7835	N	Y	300	N	17.5
MY 1999 Plym. Breeze	3073	5^{th}	357	0.63 NTE	0.70	0.10	55.0	0.72	0.81	0.27	4170	1986	N	Y	200	N	23.7
	3108	50^{th}	328	0.30 NTF	0.39	0.01	46.5	0.61	0.49	0.48	4983	4336	N	Y	288	N	22.7
MY 1999 Ford Ranger	3071	5^{th}	190	1.46 NTE	0.88	0.16	52.0	0.65	0.55	0.52	3209	2311	N	Y	150	Y	20.6
	3104	50^{th}	190	0.37 NTE	0.48	0.06	38.3	0.59	0.55	0.56	4601	3858	N	Y	285	N	20.9
MY 1999 Toyota Camry	3074	5^{th}	206	0.37 NTE	0.50	0.02	39.4	0.48	0.13	0.05	3230	2840	Y	Y	207	Unclear	18.1
	3110	50^{th}	276	0.27 NTF	0.23	0.02	35.0	0.56	0.50	0.19	5513	4217	Y	Y	308	N	20.0
MY 1999 Ford Taurus	3093	5^{th}	93	0.80 NTE	0.61	0.06	38.2	0.52	0.12	0.21	3941	3606	N	Y	168	Y	19.6
	3102	50^{th}	112	0.24 NTF	0.32	0.01	34.2	0.54	0.18	0.18	4966	4712	N	Y	281	N	21.5
PASSENGER																	
MY 1999 Hyundai Accent *	3094	5^{th}	301	0.70 NTE	0.72	0.00	44.1	0.51	0.19	0.11	5735	5523	N	Y	410	N/A	N/A
	3107	50^{th}	308	0.58 NTF	0.54	0.00	44.1	0.52	0.21	0.09	8047	8013	N	Y	550	N/A	N/A
MY 1999 Plym. Breeze	3073	5^{th}	456	0.56 NTE	0.74	0.12	50.9	0.57	0.58	0.51	3610	3976	N	Y	360	N/A	21.1
	3108	50^{th}	185	0.27 NTE	0.36	0.01	42.9	0.51	0.48	0.33	4380	4168	N	Y	460	N/A	24.4
MY 1999 Ford Ranger	3071	5^{th}	295	0.74 NTE	0.53	0.10	38.6	0.41	0.65	0.53	2656	2224	N	Y	365	N/A	22.5
	3104	50^{th}	256	0.33 NTE	0.39	0.04	42.6	0.40	0.36	0.28	4353	5772	N	Y	520	N/A	22.5
MY 1999 Toyota Camry	3074	5^{th}	276	0.51 NCF	0.08	0.69	37.5	0.43	0.20	0.19	3062	2117	Y	Y	388	N/A	15.6
	3110	50^{th}	165	0.18 NTE	0.16	0.20	32.7	0.53	0.10	0.15	5519	5918	Y	Y	500	N/A	16.5
MY 1999 Ford Taurus	3093	5^{th}	148	0.44 NTE	0.41	0.12	36.8	0.34	0.39	0.40	4061	2787	N	Y	340	N/A	20.7
	3102	50^{th}	102	0.24 NTE	0.28	0.00	31.9	0.44	0.46	0.35	5091	4028	N	Y	430	N/A	22.1

* The MY 1999 Hyundai Accent did not have a passenger air bag. (The vehicle was purchased in the Canadian market where air bags are not federally mandated).

Table A2: Unbelted 48 kmph (30 mph) Rigid Barrier Crash Test Results.

	Test #	Dummy Size	HIC15	Nij	Normalized Neck Tension	Normalized Neck Compression	Chest Acceleration (Gs)	Normalized Deflection	Normalized Left Femur	Normalized Right Femur	Chest to Steering Wheel or Instrument Panel Distance (mm)
DRIVER											
MY 1999 Saturn SL1	3113	5th	106	0.31 NTF	0.38	0.01	37.0	0.60	0.52	0.36	202
	3127	50th	128	0.33 NTF	0.27	0.05	36.8	0.74	0.49	0.53	350
MY 1999 Dodge Intrepid	3118	5th	139**	1.36 NTE	0.62	0.06	56.6	1.02	0.39	0.70	178
	3126	50th	403	0.35 NTE	0.49	0.05	54.4	0.71	0.53	0.78	265
MY 1999 Toyota Tacoma	3119	5th	199	0.39 NTF	0.51	0.05	52.3	0.99	0.78	0.91	215
	3128*	50th	176	0.25 NTF	0.29	0.25	43.7	0.77	0.88	0.53	338
MY 1999 Acura 3.5 RL	3211	5th	149	1.29 NTE	0.63	0.02	47.4	0.79	0.46	0.57	208
	3125	50th	154	0.24 NTF	0.18	0.03	56.9	0.50	1.33	0.53	361
MY 1999 Ford Econoline	3213	5th	110	0.93 NTE	0.57	0.03	43.1	0.49	0.72	0.68	224
	3123	50th	87	0.22 NTF	0.33	0.14	52.1	0.59	0.62	0.58	291
MY 1999 Chevrolet Blazer	3222	5th	105	0.32 NTF	0.42	0.07	44.5	0.78	0.90	0.63	203
	3245	50th	152	0.34 NTF	0.53	0.05	63.1	0.99	0.78	0.85	345
PASSENGER											
MY 1999 Saturn SL1	3113	5th	276	0.62 NTF	0.69	0.03	44.7	0.29	0.45	0.48	367
	3127	50th	200	0.31 NTE	0.49	0.15	40.2	0.15	0.64	0.52	466
MY 1999 Dodge Intrepid	3118	5th	302	0.56 NCE	0.55	0.24	62.2	0.25	0.75	0.60	410
	3126	50th	223	0.35 NCE	0.23	0.32	54.1	0.41	0.75	0.79	650
MY 1999 Toyota Tacoma	3119	5th	380	2.29 NTE	1.50	0.41	42.2	0.08	0.88	0.72	424
	3128*	50th	173	0.48 NTF	0.73	0.19	35.6	0.37	0.50	0.64	539
MY 1999 Acura 3.5 RL	3211	5th	306	0.78 NCE	0.32	0.37	55.5	0.24	0.53	0.68	407
	3125	50th	367	0.41 NCF	0.12	0.24	49.8	0.18	0.68	0.77	645
MY 1999 Ford Econoline	3213	5th	210	0.29 NTF	0.30	0.09	42.2	0.30	0.50	0.66	476
	3123	50th	226*	0.32 NTF	0.15	0.16	45.8	0.12	0.62	0.80	570
MY 1999 Chevrolet Blazer	3222	5th	255	1.18 NCE	0.50	0.11	45.7	0.21	0.58	0.60	354
	3245	50th	289	0.34 NTF	0.43	0.19	51.8	0.24	0.60	0.56	475

* Integrated vehicle accelerometer channels did not yield proper change in velocity. Impact speed is in question for this test.
** Head acceleration in z direction is bad. HIC computation used x & y signals only.

Table A3: Supplemental Belted 5th Percentile Female 48 kmph (30 mph) Rigid Barrier Crash Test Results.

	Test #	HIC15	Nij	Normalized Neck Tens.	Normalized Neck Comp.	Chest Accel. (Gs)	Normalized Chest Defl.	Normalized Left Femur	Normalized Right Femur
DRIVER									
MY 1999 Geo Metro	3072	92	1.50 NTE	0.73	0.29	48.4	0.58	0.31	0.30
MY 1998 Nissan Maxima	3067	129	1.73 NTE	0.97	0.05	43.3	0.47	0.08	0.13
MY 1998 Chevrolet Malibu	3066	185	0.62 NCE	0.59	0.23	39.6	0.53	0.38	0.13
MY 1998 Chevrolet Venture	3070	402	0.50 NTE	0.72	0.11	34.5	0.53	0.19	0.27
MY 1998 Ford Windstar	3069	106	0.38 NTE	0.32	0.11	37.1	0.48	0.34	0.12
MY 1998 Subaru Forester	3068	157	0.81 NTE	0.80	0.08	48.6	0.62	0.38	0.30
MY 1999 Acura 3.5 RL	3095	219	1.42 NTE	0.85	0.29	43.3	0.70	0.03	0.03
MY 1999 Dodge Intrepid	3098	214	0.68 NTE	0.61	0.12	49.1	0.61	0.13	0.55
MY 1999 Chevrolet Cavalier	3096	291	0.63 NTE	0.64	0.15	51.9	0.50	0.41	0.27
MY 1999 Chevrolet Cavalier	3179	200	0.93 NTE	0.68	0.14	45.6	0.50	0.45	0.17
MY 1999 Chevrolet Cavalier	3180	247	0.73 NTE	0.64	0.11	51.8	0.53	0.46	0.51
MY 1998 Nissan Altima	2858	141	0.46 NTE	0.57	0.07	42.0	0.41	0.30	0.50
MY 1998 Honda Accord	2862	225	1.07 NTE	0.63	0.13	46.5	0.62	0.24	0.11
MY 1998 Plymouth Voyager	2865	255	0.43 NTF	0.60	0.15	45.1	0.83	0.37	0.50
MY 1998 Ford Explorer	2864	154	1.47 NTE	0.83	0.11	58.1	0.77	0.54	0.42
MY 1998 Nissan Sentra	2863	199	0.51 NTE	0.52	0.00	37.3	0.39	0.48	0.22
MY 1998 Dodge Neon	2861	354	0.50 NTF	0.76	0.13	48.9	0.56	0.50	0.50
MY 1998 Mazda 626	2866	220	1.69 NTE	0.82	0.26	47.4	0.46	0.03	0.36
MY 1998 Nissan Frontier	2867	436	0.79 NTE	0.62	0.17	47.5	0.78	0.05	0.03
MY 1998 Toyota Corolla	2859	324	0.59 NTE	0.75	0.14	36.5	0.35	0.32	0.31
MY 1998 Toyota Tacoma	2860	545	0.77 NTE	1.04	0.17	58.3	0.82	0.27	0.05
MY 1998 Honda Civic	3065	108	0.75 NTE	0.60	0.08	38.8	0.46	0.19	0.25
PASSENGER									
MY 1999 Geo Metro	3072	52	0.47 NTF	0.25	0.44	42.0	0.31	0.41	0.43
MY 1998 Nissan Maxima	3067	192	0.35 NTF	0.21	0.44	44.3	0.36	0.51	0.28
MY 1998 Chevrolet Malibu	3066	224	0.35 NTF	0.21	0.19	37.7	0.50	0.41	0.24
MY 1998 Chevrolet Venture	3070	121	0.57 NTE	0.46	0.20	31.8	0.47	0.30	0.27
MY 1998 Ford Windstar	3069	67	0.44 NTE	0.33	0.03	32.9	0.41	0.34	0.28
MY 1998 Subaru Forester	3068	65	0.60 NTE	0.41	0.11	41.6	0.46	0.39	0.62
MY 1999 Acura 3.5 RL	3095	357	0.37 NTE	0.39	0.21	51.1	0.66	0.40	0.04
MY 1999 Dodge Intrepid	3098	199	0.47 NTE	0.41	0.14	38.2	0.49	0.49	0.21
MY 1999 Chevrolet Cavalier	3096	195	0.34 NTE	0.36	0.06	37.0	0.49	N/A	0.22
MY 1999 Chevrolet Cavalier	3179	210	0.38 NTE	0.42	0.10	42.9	0.55	0.12	0.21
MY 1999 Chevrolet Cavalier	3180	196	0.42 NTE	0.39	0.04	38.0	0.48	0.13	0.26
MY 1998 Nissan Altima	2858	296	0.81 NCF	0.08	0.53	39.5	0.23	0.39	0.22
MY 1998 Honda Accord	2862	269	0.42 NTE	0.40	0.10	43.7	0.44	0.55	0.33
MY 1998 Plymouth Voyager	2865	318	0.63 NTE	0.56	0.18	48.2	0.59	0.60	0.50
MY 1998 Ford Explorer	2864	155	0.42 NTE	0.48	0.23	45.5	0.41	0.58	0.50
MY 1998 Nissan Sentra	2863	244	0.42 NTE	0.41	0.12	44.6	0.52	0.26	0.24
MY 1998 Dodge Neon	2861	303	0.34 NCF	0.20	0.29	47.4	0.38	0.37	0.61
MY 1998 Mazda 626	2866	262	1.97 NTE	1.06	0.09	47.3	0.54	0.48	0.31
MY 1998 Nissan Frontier	2867	356	0.80 NCF	0.40	0.84	52.6	0.84	0.02	0.01
MY 1998 Toyota Corolla	2859	559	0.56 NCF	0.22	0.76	43.1	0.36	0.31	0.21
MY 1998 Toyota Tacoma	2860	300	0.93 NTE	0.55	0.15	61.8	0.69	0.28	0.41
MY 1998 Honda Civic *	3065	144	0.49 NTF	0.54	0.15	40.7	0.49	0.39	0.52

* The MY 1999 Honda Civic did not have a passenger air bag. (The vehicle was purchased in the Canadian market where air bags are not federally mandated).

Table A4: Supplemental Belted 50th Percentile Male 48 kmph (30 mph) Rigid Barrier Crash Test Results.									
	Test #	HIC15	Nij	Normalizd Neck Tens.	Normalized Neck Comp.	Chest Accel. (Gs)	Normalized Chest Defl.	Normalized Left Femur	Normalized Right Femur
DRIVER									
MY 1999 Volkswagen Beetle	3111	228	0.27 NTF	0.32	0.04	39.9	0.55	0.20	0.27
MY 1999 Saturn SC1	3109	204	0.35 NTF	0.25	0.01	29.9	0.52	0.16	0.06
MY 1999 Ford Mustang	3101	173	0.31 NTF	0.40	0.08	34.9	0.50	0.24	0.43
MY 1999 Ford Crown Victoria	3103	206	0.30 NTF	0.46	0.04	33.8	0.55	0.44	0.23
MY 1999 Ford Windstar	3090	81	0.20 NTF	0.20	0.01	28.9	0.49	0.24	0.46
MY 1999 Ford Expedition	3105	174	0.30 NTE	0.39	0.08	39.7	0.58	0.36	0.34
MY 1999 Dodge Ram 1500	3100	361	0.37 NTE	0.49	0.09	34.4	0.59	0.48	0.16
MY 1999 Toyota Sienna	3087	300	0.24 NTF	0.22	0.03	37.6	0.50	0.29	0.23
MY 1999 Suzuki Vitara	3088	309	0.42 NTE	0.37	0.02	31.7	0.61	0.37	0.51
MY 1999 Honda Odyssey	3089	101	0.15 NTF	0.22	0.00	31.7	0.46	0.25	0.18
MY 1999 Nissan Pathfinder	3091	392	0.25 NTE	0.35	0.07	36.6	0.54	0.22	0.07
MY 1999 Volkswagen Eurovan	3092	458	0.45 NTE	0.51	0.01	39.3	0.69	0.47	0.46
MY 1999 Honda Civic	3106	74	0.21 NTE	0.31	0.04	36.7	0.54	0.35	0.23
PASSENGER									
MY 1999 Volkswagen Beetle	3111	191	0.20 NTF	0.29	0.01	39.8	0.43	0.43	0.40
MY 1999 Saturn SC1	3109	133	0.21 NTF	0.20	0.00	25.8	0.37	0.22	0.15
MY 1999 Ford Mustang	3101	85	0.19 NTF	0.23	0.01	33.8	0.50	0.41	0.18
MY 1999 Ford Crown Victoria	3103	108	0.33 NTE	0.36	0.02	31.8	0.50	0.23	0.25
MY 1999 Ford Windstar	3090	100*	0.18 NTF	0.20	0.01	30.2	0.56	0.17	0.31
MY 1999 Ford Expedition	3105	158	0.28 NTE	0.41	0.06	37.0	0.60	0.20	0.21
MY 1999 Dodge Ram 1500	3100	165	0.45 NTE	0.39	0.08	38.4	0.51	0.21	0.20
MY 1999 Toyota Sienna	3087	240	0.32 NTE	0.30	0.01	38.1	0.58	0.37	0.17
MY 1999 Suzuki Vitara	3088	166	0.36 NTE	0.30	0.15	37.1	0.46	0.35	0.27
MY 1999 Honda Odyssey	3089	135	0.20 NTF	0.28	0.01	27.5	0.44	0.25	0.29
MY 1999 Nissan Pathfinder	3091	169	0.33 NTF	0.32	0.08	39.0	0.59	0.31	0.22
MY 1999 Volkswagen Eurovan	3092	286	0.32 NTE	0.52	0.12	40.2	0.61	0.25	0.39
MY 1999 Honda Civic **	3106	106	0.35 NTF	0.36	0.02	38.1	0.52	0.28	0.15

*Head acceleration in z direction is bad. HIC computation used x & y signals only.
** The MY 1999 Honda Civic did not have a passenger air bag. (The vehicle was purchased in the Canadian market where air bags are not federally mandated).

Table A5: Seat Position Comparison - Unbelted 5th Percentile Female 48 kmph (30 mph) Rigid Barrier Crash Test Results.									
	Test #	HIC15	Nij	Normalized Neck Tens.	Normalized Neck Comp.	Chest Accel. (Gs)	Normalized Chest Defl.	Normalized Left Femur	Normalized Right Femur
DRIVER									
MY 1999 Acura 3.5 RL (full-forward)	3211	149	1.29 NTE	0.63	0.02	47.4	0.79	0.46	0.57
MY 1999 Acura 3.5 RL (76 mm back from full-forward)	3244	68	0.74 NTE	0.46	0.07	48.4	0.75	0.51	0.83